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Summer food habits and gill raker morphology of seven Catostomid species in Iowa rivers

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CHAPTER ONE

GENERAL INTRODUCTION

The family Catostomidae (commonly referred to as suckers) consists of 76 species of fish, 75 of which are native to North America (Cooke et al. 2005). Historically, 17 species are believed to have naturally occurred in Iowa. Of those 17 species, two, lake chubsucker *Erimyzon sucetta* and greater redhorse *Moxostoma valenciennesi,* have been extirpated from the state and the status of five others, river redhorse *Moxostoma carinatum,* black redhorse *M. duquesnei,* silver redhorse *M. anisurum,* highfin carpsucker *Carpiodes velifer,* and black buffalo *Ictiobus niger,* is either declining or unknown (Zohrer 2006).

Traditionally, catostomids have received much less study than prominent riverine game species (e.g., smallmouth bass *Micropterus dolomieui* and channel catfish *Ictalurus punctatus*). However, suckers, along with numerous small bodied fishes, are likely the base of fish assemblages in the rivers of Iowa. In the past, the food habit of suckers have often been referred to in vague terms such as bottom ooze or muck, both in the literature and government agency descriptions. In addition to this limited amount of base information, these fish are often placed into the same category as invasive Asian carps, as "rough" fish by many of the agencies that govern fisheries. Perhaps it is not surprising that the opinion of many people toward suckers is not very positive and that they are most often thought of as valueless or nuisance fish, despite the fact that they are important native species (Becker 1983).

Like most other native species, suckers have and are facing many of the same changes and challenges that have caused 68 of the 144 native fish species of Iowa to be

identified as species of greatest conservation need (Zohrer 2006). Since the arrival of European settlers in Iowa, the landscape of the state has undergone massive changes. Agriculture has caused changes to occur on over 80% of the land in Iowa (Natural Resources Conservation Service 2000). Changes to the watersheds of rivers have been shown to have many negative effects on fish communities through changes in: habitat (from increased sedimentation), increased temperature (from the removal of stream side vegetation), declines in macroinvertebrate community diversity and biomass, and decreased egg and larval fish survival because of increased fine sediment loads. (Morgan et al. 1983; Cooper 1987; Holopainen and Huttunen 1992). Increased agricultural land use is typically associated with declines in fish community diversity and biomass (Karr et al. 1985; Walser and Bart 1999). Much of the change that occurred to the landscape of Iowa happened before the advent of modern fisheries management and techniques, so there is little historical data about native sucker ranges, growth, food habits or abundances prior to the arrival of European settlers.

The wide diversity of catastomid species in the state of Iowa is very unique with 17 species from seven genera (i.e., *Cycleptus, Erimyzon, Ictiobus, Carpiodes, Moxostoma, Minytrema* and *Hypentelium)* believed to natural occur in the states lakes, streams and rivers (Zohrer 2006). Several of these families contain multiple species that are externally morphologically similar and often occur side by side in the same body of water. The changes that have occurred to aquatic ecosystems in Iowa may have benefited some species and had detrimental effects on others depending on their feeding ecology and habitat requirements.

Successful management of fish species depends on understanding their basic ecological requirements. For instance, estimating dynamic rate functions like growth and mortality for a population requires the ability to obtain precise estimates of age. Previous age

and growth studies of golden redhorse *Moxostoma erythrurum,* shorthead redhorse *M. macrolepidotum,* silver redhorse *M. anisurum* and northern hogsucker *Hypentelium nigricans* obtained precise estimates of age from pectoral fin rays (Reid 2007). However, previous attempts at ageing *Carpiodes* spp. (highfin carpsucker, quillback carpsucker *C. cyprinus*, and river carpsucker *C. carpio*) have focused on the use of scales or the second dorsal fin ray (Buchholz 1957; Al-Rawi 1965; Morris 1965; Braaten et al. 1999) with poor precision reported for age estimates.

In addition to the limited information about basic growth and mortality, the food habits of catostomid species have not previously been examined when several species are found within the same fish assemblage. Many catostomids have a similar external feeding morphology like a subterminal mouth that is presumably well adapted to a benthic feeding style. However, the internal feeding morphology of catostomids (i.e., gill raker length and spacing) has not been examined to see if it varies among species and within genus.

The goals of this research were to: 1. determine if pectoral fin rays provide a more precise age estimate of *Carpiodes* spp. than scales and 2. examine food habit overlap, gill raker morphology and growth of catostomid species in Iowa rivers.

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CHAPTER TWO

PRECISION OF SCALES AND PECTORAL FIN RAYS FOR ESTIMATING AGE OF HIGHFIN CARPSUCKER, QUILLBACK CARPSUCKER AND RIVER CARPSUCKER

Abstract

Previous attempts to age *Carpiodes* spp. have focused on the use of scales or dorsal fin rays. Past studies indicate that obtaining age estimates from these structures in other species is difficult and inconsistent. We examined between reader precision of age estimates of scales and pectoral fin rays for 123 highfin carpsuckers *Carpiodes velifer*, 174 quillback carpsuckers *C. cyprinus* and 135 river carpsucker *C. carpio*. Precision of age estimates was assessed through measures of agreement, the coefficient of variation (CV), and a confidence rating. Exact agreement between readers was higher for fin rays (highfin carpsucker = 82.1%; quillback carpsucker = 75.9%; river carpsucker = 77.0%) than scales (highfin carpsucker = 69.5%, quillback carpsucker = 68.9%; river carpsucker = 71.1%). In addition, CV was lower for fin rays (highfin carpsucker = 2.28; quillback carpsucker = 2.43; river carpsucker = 2.90) than scales (highfin carpsucker = 2.95; quillback carpsucker = 3.00; river carpsucker = 3.46). Fin rays were also assigned a higher confidence rating (i.e., mean readability, 0-3 with 3 being high; highfin carpsucker = 2.22; quillback carpsucker = 1.95; river carpsucker = 1.92) than scales (highfin carpsucker = 1.53; quillback carpsucker = 1.51; river carpsucker = 1.68).

Introduction

The highfin carpsucker *Carpiodes velifer*, quillback carpsucker *C. cyprinus*, and river carpsucker *C. carpio*, are native species common throughout central North America. Highfin carpsucker and quillback carpsucker are listed by Kansas and Illinois as species of greatest conservation need (Becker 2005; Wasson et al. 2005). In Iowa, the status of river carpsucker and quillback carpsucker is considered to be stable; however, the status of the highfin carpsucker is unknown (Zohrer 2006).

Throughout their distribution, carpsuckers have experienced the same changes to habitat that have caused 68 of the 144 native fish species of Iowa to be identified as species of greatest conservation need (Zohrer 2006). Increased agricultural land use is typically associated with declines in fish assemblage diversity and biomass (Karr et al. 1985; Walser and Bart 1999) and agriculture has altered over 80% of the land in Iowa (Natural Resources Conservation Service 2000). Changes to the watersheds of rivers have been shown to have many negative effects on fish communities through changes in: habitat (from increased sedimentation), increased temperature (from the removal of stream side vegetation), declines in macroinvertebrate community diversity and biomass, and decreased egg and larval fish survival because of increased fine sediment loads. (Morgan et al. 1983; Cooper 1987; Holopainen and Huttunen 1992). Because *Carpiodes* spp. are typically a major component of lotic fish assemblages, additional information on their population dynamics is needed to better understand the ecology of large river systems.

The ability to obtain precise estimates of age is fundamental to the estimation of dynamic rate functions such as mortality and recruitment. Traditionally, a variety of structures have been used to estimate the age of fishes (i.e., scales, otoliths, dorsal spines,

pectoral fin rays, opercles), but the structure that provides the greatest accuracy and precision often varies among species and geographic location (DeVries and Frie 1996; Jackson et al. 2007). Given the importance of age and growth information, determining the best structure for aging should be a high priority.

The age and growth of river carpsuckers has been studied using scales (Buchholz 1957; Al-Rawi 1965; Morris 1965); however, most have indicated difficulty in using scales. A more recent study by Bratten et al. (1999) evaluated the use of the second dorsal fin ray as an alternative aging structure. They found that percent exact agreement was only slightly higher for fin rays (71%) than scales (68%), and despite the previous concerns with the use of scales for aging river carpsuckers, the authors concluded that river carpsucker scales should be used for fish less than 400 mm in length and fin rays for fish longer than 400 mm. In contrast to river carpsuckers, aging of highfin carpsuckers and quillback carpsuckers has been largely ignored.

Pectoral fin rays have become an increasingly common structure for estimating the age of fish (Metcalf 2005; Maceina et al. 2007; Quist et al 2007). Pectoral fin rays can be removed non-lethally, which is particularly important when working with rare or threatened species. The processing time of fin rays has also been shown to be substantially less than otoliths (Isermann et al. 2003). Fin rays have also been shown to provide more precise age estimates than scales for several species such as common carp *Cyprinus carpio* and white sucker *Catostomus commersonii* (Jackson et al. 2007; Quist et al. 2007). In addition, fin rays have been shown to provide age estimates that are very similar to age estimates from otoliths for a variety of fish species, including Pacific cod *Gadus macrocephalus,* Atlantic sturgeon *Acipenser oxyrinchus*, walleye *Sander vitreus*, rainbow smelt *Osmerus mordax* and several

catostomid species (Beamish 1981; Stevenson and Secor 2000; Isermann et al. 2003; Quist et al. 2007; Walsh et al. 2008). The objective of this study was to evaluate precision of age estimates from pectoral fin rays and scales for highfin carpsucker, quillback carpsucker, and river carpsucker.

Methods

Highfin carpsucker, quillback carpsucker and river carpsuckers were sampled from four non-wadeable rivers in Iowa. The rivers included the Boone, North Raccoon, Shell Rock, and Wapsipinicon rivers. A 3-km reach of each river was sampled using a DC electrofishing unit (Smith Root VVP-15B; Smith Root Inc. Vancouver, WA). Collected fish were measured to the nearest mm and weighed to the nearest gram. The left marginal pectoral fin ray was removed by cutting just proximal to the articulation point where the fin ray joined the body wall and then separated from the rest of the fin (Koch et al. 2008). Approximately 10-15 scales were removed from the area just posterior to the insertion of the pectoral fin. Fin rays and scales were placed into labeled coin envelopes and allowed to air dry.

After drying, fin rays were mounted in epoxy in preparation for age and growth analysis using the methods described in Koch and Quist (2007). Fin rays were cut into 1.0 mm sections using a Buehler Isomet low speed saw (Buehler Inc., Lake Bluff, Illinois). Sections were taken from the proximal end of the spine, as this area of the fin ray has been shown to provide the highest quality sections and greatest precision among readers for other fish species (Sneed 1951; Koch and Quist 2008). Sections were aged with a microscope connected to a computer and then evaluated with the aid of image analysis software. A minimum of eight scales from each fish were pressed onto acetate slides (40 mm wide × 70

mm long × 1 mm thick). Scale impressions were aged on a microfiche reader at 44× magnification.

Two readers independently aged the fin rays and scales once. Readers assigned ages to structures without knowledge of age estimates of the other structure or age estimates of the other reader. Precision between readers for scales and fin rays was assessed by plotting the age estimates from reader 1 against the age estimates of reader 2, and examining the proximity of the mean age with 95% confidence intervals to the equivalence line (Campana et al. 1995). Percent exact agreement and agreement within one year was calculated for each structure to evaluate precision of age estimates between readers. The coefficient of variation (CV) was calculated for each individual fish and aging structure and then averaged to estimate between reader precision for each structure. A paired *t*-test was used to estimate whether age estimates differed between fin rays and scales (Campana et al. 1995).

In addition to aging the structures, a confidence rating (i.e., readability) was assigned to each age estimated for a structure based on a 0 to 3 scale that was similar to the one used by Fitzgerald et al. (1997) and Koch and Quist (2008). For structures rated 0, the reader had no confidence in the age they assigned, while structures assigned a rating of 3 were considered to exhibit a clear age. Previous uses of confidence ratings have relied on ratings that lack clear criteria, and higher ratings have not always been correlated with increased precision of age estimates (Fitzgerald et al. 1997). To increase the consistency of confidence ratings within and among readers, we developed guiding criteria for the assignment of ratings. The criteria used to assign ratings are provided in Table 1. A *t*-test was used to determine if mean confidence ratings assigned to scales and pectoral fin rays differed. Results from all *t*-tests were considered significant at $\propto = 0.05$

Results

Four hundred and thirty two carpsuckers were aged (Table 2). Highfin carpsucker varied in total length from 220 to 423 mm, quillback carpsucker varied from 187 to 480 mm, and river carpsucker varied from 170 to 441 mm. Examination of the age bias plots (Figure 1) indicated that readers did not consistently overestimate or underestimate of ages for fin rays and scales collected from the studied species. Precision between readers tended to be low for scales, indicating greater variation in age estimates between readers for scales than for fin rays. Precision of both scales and fin rays decreased as age increased (Figure 1). Exact agreement in age estimates between readers was higher for fin rays than scales for highfin carpsucker (fin ray = 82.1%; scale = 69.5%), quillback carpsucker (fin ray = 75.9%; scale = 68.9%) and river carpsuckers (fin ray = 77.0%; scales = 71.1%; Table 2).

Exact agreement between fin rays and scales was lowest for highfin carpsucker (33.1%), which was the only species that exhibited a significant difference in age between fin rays and scales ($P < 0.0001$; Table 4). Age estimates from scales of highfin carpsuckers were generally 1-3 years less than those from fin rays. For all of the species, there was no significant difference between the ages assigned to fin rays between the readers. In addition, a high percentage of age estimates between readers for fin rays were within 1 year. Age estimates within one year between readers was higher for fin rays (highfin carpsucker = 100.0%; quillback carpsucker = 97.7%; river carpsucker = 98.5%) than for scales (highfin carpsucker = 93.3%; quillback carpsucker = 94.8%; river carpsucker = 95.5%; Table 3). Fin rays also had a lower mean between reader CV than scales (Table 4). However, within reader exact agreement between fin rays and scales was less than 50% for all species and both readers (Table 4).

The mean confidence rating was significantly higher for fin rays in all three species ($P < 0.001$; Table 2). Additionally, as confidence rating for a structure increased, between reader agreement also increased (Table 4). For example, exact agreement of fin rays from highfin carpsucker rated 1, 2, and 3 was 61.1, 76.3, and 93.5% respectively. Similarly, percent agreement increased for scales as confidence ratings increased.

Discussion

Previous attempts at aging *Carpiodes* spp. have primarily focused on the use of scales (Buchholz 1957; Al-Rawi 1965; Morris 1965; Woodward and Wissing 1976). The authors of these studies indicated that obtaining age estimates from scales was often difficult due to a lack of "cutting over" at annulus formation or impossible because the scales were unreadable. In addition, previous studies of aging *Carpiodes* spp. had questionable ages due to the high prevalence of false annuli. Water level fluctuations, changes in water temperature, starvation, and low dissolved oxygen can all cause scales to develop false annuli (Wyel and Booth 1999). The frequent occurrence of false annuli in the scales of carpsuckers may be reflective of the constantly changing environment of river systems. In contrast to scales, calcified structures such as otoliths and fin rays have been shown to be less susceptible to the formation of false annuli during periods of stress (Marshall and Parker 1982; Campana 1983).

Many of the studies that have examined the use of scales for estimating ages have shown that precision in age estimates varies greatly among species. For instance, scales have been shown to provide precise ages for several centrachid species, including largemouth bass *Micropterus salmoides* (Long and Fisher 2001) and bluegills *Lepomis macrochirus* (Reiger 1962); however, scales have also been shown to underestimate the age of fish (Erickson

1983; Isermann et al. 2003). Although the current study cannot evaluate accuracy of age estimates; percent agreement between readers for scales (i.e., 65-70%) was similar to values previous reported for river carpsuckers in the Des Moines (Morris 1965) and in the Missouri rivers (Bratten et al. 1999). The authors of these papers stated that obtaining age estimates from scales was often difficult and that a high percentage of scales (~10%) were unreadable. Both readers in the current study noted that reading scales from many of the fish was difficult and that precision would likely have been less if fewer scale impressions had been made. Often, only one or two out of 8-12 scale impressions were used for age estimation.

Similar to scales, previous research has shown that the accuracy and precision of age estimates from fin rays tends to vary between species. For instance, fin rays did not provide precise or accurate for age estimates of pallid sturgeon *Scaphirhynchus albus* (Hurley et al. 2004) and white sturgeon *A. transmontanus* (Rien and Beamesderfer 1994). However, fin rays had higher precision and more accurate age estimates than otoliths in rainbow smelt (Walsh et al. 2008). Quist et al. (2007) found that age estimates were similar between fin rays and otoliths for bluehead sucker *Catostomus discobolus*, flannelmouth sucker *C. latipinnis*, and white sucker *C. commersonii.* Additionally, the scales of these same catastomid species provided age estimates that were substantially less than those obtained from fin rays and otoliths (Quist et al. 2007). In the current study, pectoral fin rays typically had a higher age estimate than scales. Most importantly, pectoral fin rays had the highest percent agreement, highest confidence ratings, and the lowest CVs for all three species.

Although there have been several previous attempts at aging carpsuckers (including the current study), no study has validated the age assignments or growth estimates. Pectoral fin rays provide a more precise estimate of age than scales and would be a good choice for a

future validation study. Fin rays also have the added benefit of not requiring the sacrifice of fish in areas where the population status is unknown or declining. Based on this research, we recommend that researchers use pectoral fin rays for aging carpsuckers.

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Table 1.—Criteria used to assign confidence ratings to scales and fin rays from *Carpiodes* spp. sampled from four Iowa rivers, 2009.

Confidence Rating	Guidelines for assigning confidence ratings
	Scales
0	Disagreement between scales > 2 years. Most annuli lack cutting over. Annuli do not exhibit tightly spaced rings. Checks present.
1	Disagreement between scales < 2 years. Some annuli exhibit cutting over. Checks present.
2	Disagreement between scales maximum of 1 year. Cutting over apparent on many annuli.
3	No disagreement between scales. Cutting over present for majority of annuli. Annuli exhibit tightly packed rings and easy to identify.
	Fin rays
0	Focus highly eroded. Most annular rings hard to identify. Wide or double rings apparent. Error may be $\geq$ 2 yrs.
1	Focus slightly eroded. Checks present. Majority of annuli easily identified but may have double rings. Error likely < 2 yrs.
2	Focus intact. Most annular rings well defined. Minimal checks present. Error within 1 yr.
3	Focus intact. Annular rings well defined.

Table 2.—Precision in age estimates between two readers for pectoral fin rays and scales obtained from *Carpiodes* spp. sampled from rivers in Iowa, 2009. Measures of precision include percent exact agreement (PA-0), percent agreement within 1 year (PA-1), mean CV (%), and confidence rating (CR).

Species and Structure	PA-0	PA-1	CV	CR
Highfin carpsucker				
Scale	69.5	93.3	2.95	1.53
Fin Ray	82.1	100.0	2.28	2.22
Quillback carpsucker				
Scale	68.9	94.8	3.00	1.51
Fin Ray	75.9	97.7	2.43	1.95
River carpsucker				
Scale	71.1	95.5	3.46	1.68
Fin Ray	77.0	98.5	2.90	1.92

Table 3.—Within reader exact agreement (%) of age estimates between scales and fin rays for *Carpiodes* spp. sampled from four Iowa rivers, 2009.

	Highfin carpsucker	Quillback carpsucker	River carpsucker
Reader 1	33.1	48.9	43.0
Reader 2	34.7	46.0	43.0

Table 4.—Number of ratings (*N*) and between reader exact agreement at different confidence ratings (CR) for scales (%SA) and pectoral fin rays (%FRA) for *Carpiodes* spp. sampled from four Iowa rivers, 2009.

Species	CR	*N*	%SA	*N*	%FRA
Highfin carpsucker					
	0	3	66.6	0	
	1	54	63.0	18	61.1
	2	54	79.6	59	76.3
	3	7	85.7	46	93.5
Quillback carpsucker					
	0	10	50.0	1	100
	1	90	60.0	55	65.5
	2	44	72.7	68	77.9
	3	25	96.0	50	88.0
River carpsucker					
	0	3	33.3	0	
	1	55	71.0	46	65.2
	2	58	69.0	54	77.8
	3	19	73.6	35	85.7

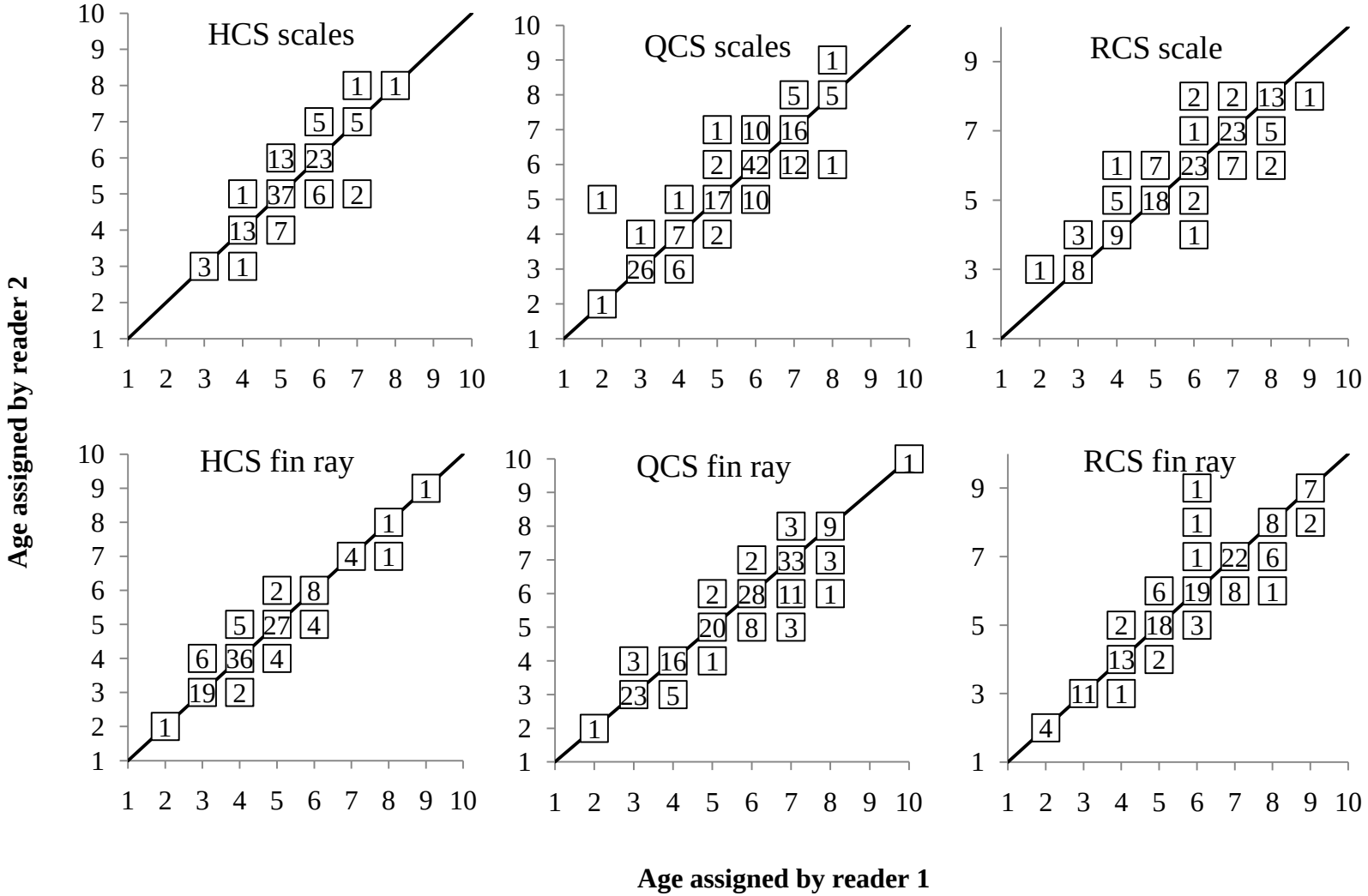

Figure 1.— Age bias plots comparing agreement between readers for highfin carpsucker (HCS), quillback carpsucker (QCS) and river carpsucker (RCS) for pectoral fin rays and scales for *Carpiodes* spp. sampled from Iowa rivers, 2009. Diagonal lines represent exact agreement between readers. Numbers in squares represent the number of *Carpiodes* spp. at each age.

CHAPTER THREE

SUMMER FEEDING HABITS AND GILL RAKER MORPHOLOGY OF SEVEN CATASTOMID SPECIES IN IOWA RIVERS

Abstract

Food habits, diet overlap and gill raker morphology of highfin carpsucker *Carpiodes velifer*, quillback carpsucker *C. velifer*, river carpsucker *C. carpio*, golden redhorse *Moxostoma erythrurum*, shorthead redhorse *M. macrolepidotum*, silver redhorse *M. anisurum*, and northern hogsucker *Hypentelium nigricans* in four Iowa rivers. Diet overlap of invertebrates among all species was calculated with Morista's index (*C*). Food habit niche width was quantified with Levin's index (*B*) and similarity of gill raker morphology was compared with analysis of covariance. Values from Morista's index suggested significant overlap in the diets of highfin carpsucker and river carpsucker ($C = 0.81$), quillback and river carpsucker ($C = 0.66$), and shorthead redhorse and silver redhorse ($C = 0.67$). Levin's index showed that golden redhorse, quillback carpsucker, and river carpsucker had the most generalized feeding strategies as their food niche widths were substantially wider than other species (golden redhorse $B = 0.32$; quillback carpsucker $B = 0.53$; river carpsucker $B = 0.41$). Gill raker length and spacing were positively correlated with the standard length of the fish for all species (length: $r^2 = 0.67\text{-}0.88$, $P \leq 0.01$; spacing: $r^2 = 0.63\text{-}0.73$, $P \leq 0.01$). Comparisons of the slope of the regression of gill raker spacing to standard lengths were not significantly different for highfin carpsucker and quillback carpsucker ($P = 0.37$), highfin carpsucker and river carpsucker ($P = 0.08$), quillback carpsucker and river carpsucker ($P = 0.10$) shorthead redhorse and golden redhorse ($P = 0.76$), golden redhorse and silver redhorse

($P = 0.07$). Differences in gill raker morphology allow the sampled catostomid species to utilize different aquatic invertebrate species and reduce competition.

Introduction

The family *Catostomidae* consists of 76 species of fish that are widely distributed across North America (Cooke et al. 2005). Of the 17 species native to Iowa, two, lake chubsucker *Erimyzon sucetta* and greater redhorse *Moxostoma valenciennesi,* have been extirpated from the state. Additionally, the status of five others, river redhorse *Moxostoma carinatum,* black redhorse *M. duquesnei,* silver redhorse *M. anisurum,* highfin carpsucker *Carpiodes velifer,* and black buffalo *Ictiobus niger,* is either declining or unknown (Zohrer 2006).

Like most other native species, catostomids have and are facing many of the same changes and challenges that have caused 68 of the 144 native fish species of Iowa to be identified as species of greatest conservation need (Zohrer 2006). Since the arrival of European settlers in Iowa, the landscape of the state has undergone significant change. Agriculture has altered over 80% of the land in Iowa (Natural Resources Conservation Service 2000). Disturbances to the watersheds of rivers have been shown to have many negative effects on fish communities through changes in: habitat (from increased sedimentation), increased temperature (from the removal of stream side vegetation), effects on the macroinvertebrate community (decreased diversity and biomass), and decreased egg and larval fish survival (Morgan et al. 1983; Cooper 1987; Holopainen and Huttunen 1992; Litvan et al. 2007). Increased agricultural land use is also associated with declines in fish community diversity, and biomass and a shift from species with specialized food habits to species with generalized food habits (Karr et al. 1985; Walser and Bart 1999). For example,

Litvan et al. (2007) found that the placement of grade control structures made from rock riprap in silt dominated streambeds increased macroinvertebrate diversity and density. This would likely have a positive effect on the fish community of those streams. Many of the changes that occurred to the landscape of Iowa happened prior to the advent of modern fisheries management and techniques, so there is little historical data about native sucker ranges, growth, food habits or abundance.

Traditionally, fish species in the family *Catostomidae* have received much less study than prominent riverine game species (e.g., smallmouth bass *Micropterus dolomieui* and channel catfish *Ictalurus punctatus*). However, members of the *Catostomidae* family, along with small-bodied fish assemblages, are an important part of the food web of Iowa rivers (Bertrand and Gido 2007). The diversity of catostomids in the state of Iowa is high with 17 species from seven genera (i.e., *Cycleptus, Erimyzon, Ictiobus, Carpiodes, Moxostoma, Minytrema* and *Hypentelium)* native to the state's lakes, streams and rivers (Zohrer 2006). Many of these same species are externally morphologically similar and often occur side by side in the same body of water.

The conservation and management of species in the *Catostomidae* family depends on understanding the factors that affect feeding ecology (Welker and Scarnecchia 2003). Examination of food habits provides information about inter-specific interactions, niche dimension, and food resource partitioning within a fish assemblage (McNeely 1987, Gray et al. 1997).

In this study we examined feeding overlap and gill raker morphology similarities among seven species of catostomid in Iowa rivers. The objectives of this study were to: 1)

obtain basic information on the food habits of catostomids in Iowa, 2) evaluate overlap in food habits, and 3) determine if species with similar gill raker morphology have similar diets.

Methods

Three *Carpiodes* species, river carpsucker *Carpiodes carpio,* highfin carpsucker, and quillback carpsucker *C. cyprinus*, three *Moxostoma* species, shorthead redhorse *Moxostoma macrolepidotum*, golden redhorse *M. erythrurum*, and silver redhorse and northern hogsucker *Hypentelium nigricans* were sampled from four non-wadeable rivers in central and eastern Iowa during 2009. The rivers sampled were the Boone, North Raccoon, Shellrock, and Wapsipinicon. A 3-km reach of each river was sampled using a boat-mounted, pulsed DC electrofishing unit (Smith Root VVP-15B, 14014 NE Salmon Creek Ave, Vancouver, Washington). Sampling sites were selected based on fish assemblage data collected in 2007 and 2008 by Neebling and Quist (*in review*). Output was standardized to 3,000-W based on water conductivity and dropper exposure (Burkhardt and Gutreuter 1995). Each 3-km reach was seperated into six 500-m sections. Effort focused on edge channel habitats and was performed with a single pass in a downstream direction. All catostomids were collected by two netters.

Fish were processed at the end of each section, identified, measured to the nearest mm for both total (TL) and standard length (SL), and weighed to the nearest gram. Fish were euthanized with an overdose of Finquel™ (tricaine methanesulfonate; 200 mg/L) and immediately processed in the field to minimize post capture digestion. The digestive tract was removed from the esophagus back by cutting at the junction of the esophagus and at the vent (Brezner 1958). The entire digestive tract was fixed in buffered 4% formalin (Bowen

1996). The entire gill, including the pharyngeal pad, was removed from the right side of the fish and similarly preserved.

In the lab, gut contents were removed from the gizzard to the first turn of the intestine (approximately the anterior 20% of the digestive tract) and placed in a petri dish (Welker and Scarnecchia 2003). A dissecting microscope was used to further examine the samples and provide more accurate counts of invertebrates. Many of the invertebrates were severely damaged from ingestion and digestion, and identification beyond order was nearly impossible.

Several indices were used to quantify food habits. The frequency of occurrence (% F) of each food category and invertebrate taxonomic order was estimated. In addition, the number of invertebrates consumed by each fish species was used to calculate prey specific abundance (%SA).

Diet overlap between fish species was calculated using Morista's index. Morista's index is the most robust diet overlap index when prey numbers are available from stomach data, because it has the least bias for different resource distributions among species and varying sample size (Smith and Zaret 1982). Morista's index is calculated as:

$$C = \frac{2\sum_i^n P_{ij}\, P_{ik}}{\sum_i^n P_{ij}\left[\frac{n_{ij}-1}{N_j-1}\right] + \sum_i^n P_{ik}\left[\frac{n_{ik}-1}{N_k-1}\right]}$$

where C is Morista's index of niche overlap between species j and k, P_{ij} and P_{ik} are the proportion resource i is of the total resources used by species j and k respectively, n_{ij} and n_{ik} are the number of individuals of species j and k that use resource i, and N_j and N_k are the total number of each species in the sample. Coefficients of Morista's index greater than 0.60 are considered to indicate significant overlap between two species (Zaret and Rand 1971;

Angradi and Griffith 1990). In addition to Morista's index, prey importance, feeding strategy, and niche width were examined using a modification of the graphical Costello method (Amundsen et al. 1996). The modified Costello method plots prey specific abundance against frequency of occurrence for assessment of fish diets at the population level (Chipps and Garvey 2007). The location of prey items on the axis of the plot provides insight into feeding strategy (i.e., specialist or generalist), prey importance (i.e., high or low), and the contribution of prey items to niche width (Amundsen et al. 1996).

The diversity of food items consumed by catostomid species was further quantified by calculating Levin's standardized index:

$$B = [(\sum_j P_{ij}^2)^{-1} - 1](n-1)^{-1}$$

where P_{ij} is the proportion of prey *j* in predator *i*'s diet and *n* is the number of prey categories (Hurlbert 1978). The values of the index vary from 0 to 1 with 0 representing species with specialized diets and 1 representing species with generalized diets.

The gill raker structure of the first branchial arch from the right side of the body was examined for the number the width of gill raker spacing and length of gill rakers. The first branchial arch was selected because the most well developed gill rakers occur on this arch (Nelson 1967). Gill rakers located on other gill arches were markedly smaller and contribute minimally to prey retention (O'Brien 1983).

Length and width of spacing between the inner edges of gill rakers was measured for five gill rakers located in the middle of the gill arch (Tanka et al. 2006). Gill raker length and spacing was measured to the nearest 0.001 mm using a microscope connected to a computer using image analysis software. Differences in length and spacing of gill rakers among species

were tested using analysis of covariance (ANCOVA), with SL of each fish used as the covariate (Tanaka et al. 2006). ANCOVA tests were used to test if the slope of the regression of fish SL to gill raker length or spacing was statistically different between two species (i.e., are gill raker length or spacing similar for different species of fish that are the same size). If the slopes were not significantly different a second ANCOVA was used to test if the intercept was statistically different. Prior to statistical analysis, measurements of gill raker length and spacing were averaged for each individual fish. ANCOVA tests were performed for all possible species combinations for both spacing and width. Results from all statistical tests were considered significant for $P \leq 0.05$.

Results

A total of 946 stomach contents were examined in our study. Samples were taken from 174 quillback carpsucker, 123 highfin carpsucker, 135 river carpsucker, 198 golden redhorse, 214 shorthead redhorse, 60 northern hog suckers and 42 silver redhorse. Minimum, maximum and mean total length data for each species is presented in Table 1.

Most of the catostomid species exhibited generalized feeding patterns that utilized a majority of the food categories. However, some of the species exhibited specializations that placed increased importance on specific food items. For example, highfin carpsuckers utilized mollusks more than other species (%F = 23.7; %SA = 55.4; Table 2.) Golden redhorse and northern hogsuckers used Ephmeroptera more often (golden redhorse %F = 77.5; northern hogsucker %F = 66.0) and in higher numbers (golden redhorse %SA= 20.2; northern hogsucker %SA = 40.8) than the other catostomid species (Table 3). Chironomid larvae were the most numerous food item for golden redhorse, shorthead redhorse, silver

redhorse, and northern hogsucker and the third most important food item of highfin carpsucker, quillback carpsucker, and river carpsucker.

Oligochaetes and mollusks were the two most numerous food items for highfin carpsucker, quillback carpsucker, and river carpsucker (Figure 1). All *Carpiodes* spp. had a higher frequency of occurrence for algae than the other species (Table 2). The sampled catostomid species primarily consumed invertebrates associated with benthic substrates. However, the inclusion of aquatic insects that are typically found in the water column or on the surface (e.g., chironomid larvae and ephemeroptera subimagos) shows that catostomid species are able to utilize prey items found both in the water column and associated with benthic substrates.

Morista's index suggested that there were only three species pairs that overlapped significantly with regards to diet. Those pairs included highfin carpsucker and river carpsucker (C = 0.81), quillback carpsucker and river carpsucker (C = 0.66), and shorthead redhorse and silver redhorse (C = 0.67; Table 3). However, several other species pairs had moderate overlap values between 0.40 and 0.60, including golden redhorse and shorthead redhorse (C = 0.42), golden redhorse and silver redhorse (C = 0.44), highfin carpsucker and quillback carpsucker (C=0.52), northern hogsucker and shorthead redhorse (C = 0.45), northern hogsucker and silver redhorse (C = 0.48), and river carpsucker and shorthead redhorse (C = 0.42; Table 3).

Golden redhorse, quillback carpsucker, and river carpsucker had the most generalized feeding strategies. Plots of food items shows that many of the prey items occurred at relatively low %F and %SA (Figure 1). In contrast, highfin carpsucker, shorthead redhorse, silver redhorse, and northern hogsuckers had more specialized diets that focused on a few

prey items. Plots of food items shows that a few selected prey items occurred at higher %F and %SA (Figure 1).

Gill raker length and spacing was positively correlated with the SL of the fish for all species (length: r^2 = 0.67-0.88, $P \leq 0.01$; spacing: r^2 = 0.66-0.73, $P \leq 0.01$; Figures 2 and 3). Comparisons of the slope of the regression equation from comparisons of gill raker spacing to SL were not significantly different for quillback carpsucker and river carpsucker (P = 0.37), shorthead redhorse and northern hogsucker (P = 0.07), golden redhorse and silver redhorse (P = 0.07) and golden redhorse and northern hogsucker (P = 0.32; Table 2). However, the intercept was significantly different for all of the comparisons ($P \leq 0.001$). The slopes of the regression equation of gill raker spacing to SL decreased from steepest (widest spacing) to shallowest (narrowest spacing) in the following order: golden redhorse, northern hogsucker, silver redhorse, shorthead redhorse, quillback carpsucker, highfin carpsucker, and river carpsucker.

Comparison of the slope of the regression equation of gill raker length to SL were not significantly different for golden redhorse and northern hogsucker (P = 0.82), golden redhorse and shorthead redhorse (P = 0.13) and shorthead redhorse and northern hogsucker (P = 0.12; Table 2). However, the intercept was significantly different for all of the comparisons ($P \leq 0.001$). The slopes of the regression of gill raker length to SL decreased from largest (longest) to smallest (shortest) in the following order: quillback carpsucker, river carpsucker, silver redhorse, highfin carpsucker, golden redhorse, northern hogsucker, and shorthead redhorse.

Discussion

Previous examinations of *Carpiodes* spp. diets have varied in their conclusions about the food habits of carpsuckers. In the upper Missouri River, river carpsuckers fed primarily on zooplankton (Welker and Scarnecchia 2003). In contrast, river carpsuckers from the lower Missouri River fed on a variety of food items (i.e., aquatic insects, oligochaetes, plants, and mollusks; Brezner 1958). The diversity of previously reported food items is supported by the narrow gill raker spacing of *Carpiodes* spp., which allows them to efficiently retain a variety of invertebrates, zooplankton and algae. However, this morphology may also not allow them to efficiently choose the prey items they ingest, as previous studies have shown the importance of gill raker length and spacing on the size of prey items retained (Wright et al. 1983; Gillspie 2003).

Carpiodes spp. had the longest and most closely spaced gill rakers, and they were not significantly different among the three species. The narrowness of this morphology was apparent in analysis of their diets. Many individuals from all three species had gut contents that contained large amounts of algae, detritus, silt, sand, and gravel. The narrowness of the spacing between their gill rakers effectively allows them to retain nearly any sized particle removed from the river bottom or water column. This was reflected in the food niche widths of *Carpiode*s spp., which were wider than other catostomid species (except golden redhorse). The internal morphology of *Carpiodes* spp. intestines is also different than other catostomid species, as they have a small muscular organ (i.e., the "gizzard" in Brezner 1958) that appears to function as a secondary grinding mechanism before food items enter the intestine.

Although, it appears that carpsuckers are not strict invertivores because of the frequent occurrence of algae in their stomach contents, their gill raker morphology also does

not allow them to flush these items from the buccal cavity while in pursuit of invertebrates. Previous studies have shown that the ingestion of plant and algae material by fish increases during times when invertebrate biomass decreases (Schreiber and Minckley 1981) and *Capiodes* spp. are well adapted for this.

Within the *Carpiodes* spp., there was some indication of differences in feeding ecology. Highfin carpsucker and quillback carpsucker did not have significant niche overlap, which may have occurred because of differences in their preferred substrate for feeding. Highfin carpsucker gut contents more frequently contained coarser substrate (gravel %F = 55.1) than did quillback carpsucker (%F = 41.3). This increased use of coarser substrates may have allowed highfin carpsuckers to utilize mollusks at a higher rate than quillback carpsuckers (%SA = 56.5 vs. 20.3) and narrowed their feeding niche width.

Feeding differences among the *Carpiodes* spp. are also supported by the regressions of gill raker length and width. The slopes of gill raker length to SL regression equations were most different for highfin (shallowest) and quillback carpsucker (steepest), with the river carpsuckers regression equation intermediate (Figure 2). Accordingly, the diet of the river carpsucker overlapped significantly with both highfin carpsucker and quillback carpsucker.

In contrast to the *Carpiodes* spp., golden redhorse, shorthead redhorse, silver redhorse and northern hogsuckers had gill raker morphology that is better adapted to a selective invertivore feeding style. Their gill rakers were more widely spaced and shorter than those of the carpsucker species. Analysis of gut contents from these species revealed that they rarely contained algae, detritus, silt, sand or gravel. The increased space between the gill rakers of these species allows fine items to be flushed from the buccal cavity, while retaining invertebrates for consumption. An example of this was observed in the northern hogsucker,

which ingested sand and gravel during the course of feeding on invertebrates, but ejected this material prior to ingestion (Harlan et al. 1987).

Previous examinations of redhorse diets have shown that they primarily feed on invertebrates. In Meyer (1962), the diets of silver redhorse, shorthead redhorse, and golden redhorse almost entirely consisted of invertebrates with the three most important food items being Chironomidae, Ephemeroptera, and Trichoptera. Additionally, shorthead redhorse consumed primarily aquatic insects and larvae, (i.e., Diptera, Trichoptera, and Ephemeroptera) in the Mississippi River (Bur 1976). Northern hogsuckers consumed primarily benthic invertebrates (i.e., Ephemeroptera and Trichoptera) in Matheney and Rabeni (1995).

In contrast to *Carpiodes* spp., similarity of gill raker length and width regression equations between *Moxostoma* species and northern hogsuckers did not necessarily correlate with increased food habit overlap. However, the trophic overlap among *Moxostoma* spp. and northern hogsuckers was moderate (C = 0.39-0.67) and higher than overlap values of *Moxostoma* spp. and northern hogsucker with *Carpiodes* spp. (C = 0.09-0.39). Our examination of the gill raker morphology suggests why this may be occurring, as *Carpiodes* spp. have gill rakers that are significantly different (i.e., longer and narrower) than other catostomid spp. and are well adapted to feed on smaller prey items. Welker and Scarnecchia (2003) found that river carpsucker did not have significant diet overlap with white sucker *Catostomus commersoni* and longnose sucker *C. catostomus* in the upper Missouri River because it primarily consumed more abundant, but smaller, zooplankton and few of the larger and less abundant benthic invertebrates.

One possible explanation for the lack of significant diet overlap among most of the catostomid species could be simply that food resources are not limited in Iowa's rivers. When food resources are abundant, coexisting fish species exhibit greater diet overlap among species. In contrast, when food availability decreases species shift to less favored food items and overlap decreases (Werner and Hall 1976; Schoener 1982; Bettoli et al. 1991). For example, Werner and Hall (1976) showed that morphological and behavioral differences among three *Lepomis* spp. (bluegill *Lepomis macrochirus*; pumpkinseed *L. gibbosus*; and green sunfish *L. cyanellus*) allowed them to coexist. If only one of three species inhabited a system, a majority of their prey items were strongly associated with aquatic vegetation. However, when all three species are found in the same system each species still used prey associated with vegetation as an important food source, but also utilized unique morphological characteristics (e.g. gill raker differences) to supplement their diets by exploiting resources that the other species could not efficiently use. For example, bluegills have longer and more narrowly spaced gill rakers that allow them to feed on zooplankton in the water column, while pumpkinseeds have smaller more widely spaced gill rakers that allow it to sift through sediment in pursuit of benthic invertebrates. Along with this shift in diet, the rate of growth and population size also declines as greater effort has to be expended obtaining prey. Correspondingly, when released from competition all of the species exhibited faster growth rates and a shift towards larger food items (Werner and Hall 1976).

The catostomid species in the current study exhibit morphological differences in gill raker length and spacing among species, similar to the results for *Lepomis* spp. from Werner and Hall (1976), which may function to reduce diet overlap. Stomachs from all of the sampled species frequently contained chironomid larvae and pupae (the most numerous prey

items found in the sampled gut contents), which indicates that all of the species utilized these abundant prey item. However, unique morphological characteristics of the sampled catostomid species likely allowed them to utilize different portions of the invertebrate community most efficiently and reduce competition.

This study provides basic data on the food habits, gill raker morphology and growth of several species from the *Catostomidae* family in rivers of a highly disturbed landscape. Although, lake chubsucker and greater redhorse have been extirpated from the state, and the status of several other species is unknown, the dominant species of the sucker assemblage appears to be well adapted to the feed on the invertebrate assemblage of rivers in Iowa. Despite having similar external morphology, differences in gill raker morphology and the ability to utilize a variety of food resources (e.g., aquatic insects, mollusks, algae, and zooplankton) appear to allow the current sucker assemblage to coexist. Future studies are also needed to better understand the effects of diet overlap and gill raker morphology on the interactions among catostomid spp. in areas where populations are known to be declining. Additional research on the feeding ecology and morphology of catostomid species that are declining (i.e., lake chubsucker and black redhorse) is needed to better understand their habitat, food requirements and competitive interactions with the catostomid species sampled in this study. A future study that examines growth rates and diets of catostomid spp. within different catostomid assemblages would clarify the impact of competition and resource partitioning.

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Table 1.—Species, sample size (N), and total length (mm) data for highfin carpsucker, quillback carpsucker, river carpsucker, northern hogsucker, golden redhorse, shorthead redhorse, and silver redhorse sampled from Iowa rivers, 2009.

Species	N	Mean	SD	Min	Max
Highfin carpsucker	123	312.4	34.8	220	423
River carpsucker	135	356.6	56.6	170	441
Quillback carpsucker	174	349.7	71.5	187	480
Northern hogsucker	60	290.3	71.5	182	465
Golden redhorse	198	344.8	59.1	194	432
Shorthead redhorse	214	307.5	58.3	170	460
Silver redhorse	42	396.2	101.1	202	572

Table 2.—Frequency of occurrence (% F) and prey specific abundance (%SA) of prey items in the diets of catostomid spp. sampled from Iowa rivers, 2009. D (Diptera), Cl (Chironomidae larvae), Cp (Chironomidae pupae, S (Simulidae), O (Oligochaete), M (Bivalva), P (Pleocoptera), E (Ephmeroptera), Od (Odonata), Ce (Ceratopogonidae), He (Hemiptera), Hi (Hirudinea), T (Tricoptera), Co (Coleoptera), Pl (Planorbidae), Cr (Cambaridae)

Species	Index(%)	D	Cl	Cp	S	O	M	Pe	E	Od	Ce	He	Hi	T	Co	Pl	Cr	Eggs	Algae	Gravel
Highfin	F	1.7	23.1	0.9	23.9	39.8	27.3	—	—	—	—	—	—	—	—	—	—	—	87.2	55.1
Carpsucker	SA	0.4	8.3	0.2	34.0	33.3	56.5	—	0.4	—	—	—	—	—	—	—	—	—	—	—
Quillback	F	5.8	55.1	14.5	6.5	57.2	22.5	—	5.8	—	—	—	—	—	—	—	—	—	69.5	41.3
Carpsucker	SA	1.2	23.8	26.0	0.6	27.3	20.3	—	0.6	—	—	—	—	—	—	—	—	—	—	—
River	F	4.5	25.5	3.6	—	26.4	11.8	0.9	0.9	—	—	—	—	—	—	—	—	—	94.5	29.7
Carpsucker	SA	1.6	28.4	1.0	—	31.0	33.3	1.8	28.6	—	—	—	—	—	—	—	—	—	—	—
Golden	F	10.1	97.8	48.3	12.4	7.9	4.5	11.2	77.5	1.1	—	—	15.7	29.2	—	9.0	9.0	6.7	15.7	21.3
Redhorse	SA	0.6	36.6	0.9	1.5	1.3	0.7	21.1	20.2	—	—	—	4.5	4.4	—	9.6	0.5	7.2	—	—
Shorthead	F	10.6	95.7	42.6	16.0	26.6	—	11.7	25.9	—	—	—	—	—	—	19.1	—	10.6	6.3	11.5
Redhorse	SA	1.1	76.4	14.1	0.6	3.0	—	0.6	1.7	—	—	—	—	1.9	—	—	—	0.5	—	—
Silver	F	3.1	75.0	50.0	3.1	—	6.3	6.3	21.9	—	3.1	3.1	3.1	3.1	6.3	—	—	6.3	59.4	—
Redhorse	SA	0.2	58.5	16.7	0.2	—	0.6	0.7	12.1	—	0.6	0.2	0.2	0.2	0.7	—	—	9.2	—	—
Northern	F	2.0	83.7	46.9	8.2	—	2.0	4.1	66.0	2.0	4.1	—	10.2	18.4	8.2	—	—	12.2	16.7	2.0
Hogsucker	SA	0.2	41.0	5.0	1.5	—	0.1	0.2	40.8	0.1	0.2	—	1.7	2.0	0.5	—	—	6.7	—	—

Table 3.—Morista's food overlap (*C*) between species 1 and species 2, probability of gill raker length regression equation being equal between species 1 and species 2 (*P* length) and probability of gill raker spacing regression equation being equal between species 1 and species 2 (*P* spacing) for catostomids sampled from Iowa rivers, 2009.

Species 1	Species 2	Morista's *C*	*P* length	*P* spacing
Highfin carpsucker	Quillback carpsucker	0.52	0.0010	0.0001
Highfin carpsucker	Golden redhorse	0.07	0.0001	0.0020
Highfin carpsucker	Northern hogsucker	0.06	0.0001	0.0196
Highfin carpsucker	River carpsucker	0.81	0.0012	0.0483
Highfin carpsucker	Shorthead redhorse	0.10	0.0001	0.0001
Highfin carpsucker	Silver redhorse	0.09	0.0014	0.0001
Shorthead redhorse	Northern hogsucker	0.45	0.1249	0.0710
Shorthead redhorse	Golden redhorse	0.42	0.1309	0.0001
Shorthead redhorse	Silver redhorse	0.67	0.0001	0.0102
Shorthead redhorse	River carpsucker	0.42	0.0001	0.0001
Shorthead redhorse	Quillback carpsucker	0.38	0.0001	0.0010
Golden redhorse	Northern hogsucker	0.39	0.8159	0.3155
Golden redhorse	River carpsucker	0.27	0.0001	0.0002
Golden redhorse	Silver redhorse	0.44	0.0023	0.0678
Golden redhorse	Quillback carpsucker	0.25	0.0001	0.0097
Quillback carpsucker	Northern hogsucker	0.22	0.0001	0.0001
Quillback carpsucker	River carpsucker	0.66	0.0223	0.3713
Quillback carpsucker	Silver redhorse	0.38	0.0001	0.0001
River carpsucker	Silver redhorse	0.39	0.0001	0.0001
River carpsucker	Northern hogsucker	0.27	0.0001	0.0210
Northern hogsucker	Silver redhorse	0.48	0.0008	0.0033

Table 4.—Niche width (*B*) from Levin's standardized index for diets of catostomid spp. sampled from Iowa rivers, 2009.

Species	*B*
Highfin carpsucker	0.21
Quillback carpsucker	0.53
River carpsucker	0.41
Golden redhorse	0.32
Shorthead redhorse	0.09
Silver redhorse	0.12
Northern hogsucker	0.19

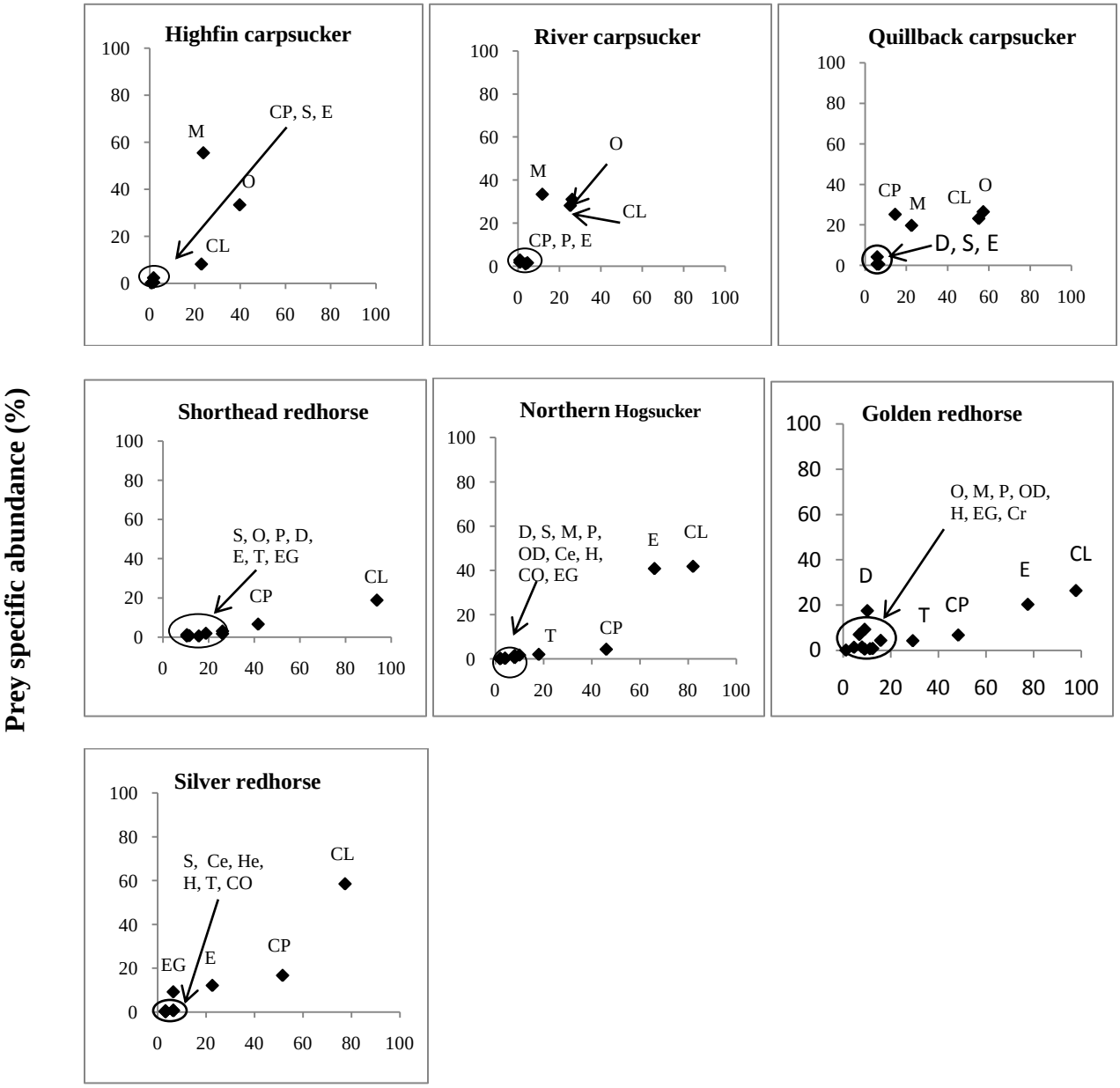

Figure 1.—Graphs of feeding strategy, prey importance, and niche width contribution of invertebrate categories for catostomid species sampled from Iowa rivers, 2009. D (diptera), Cl (Chironomid larvae), Cp (Chironomid pupae, S (Simulidae), O (Oligochaete), M (Bivalva), P (Pleocoptera), E (Ephmeroptera), Od (Odanata), Ce (Ceratopogonidae), He (Hemiptera), Hi (Hirudinea), T (Tricoptera), Co (Coleoptera), Pl (Planorbidae), Cr (Cambaridae)

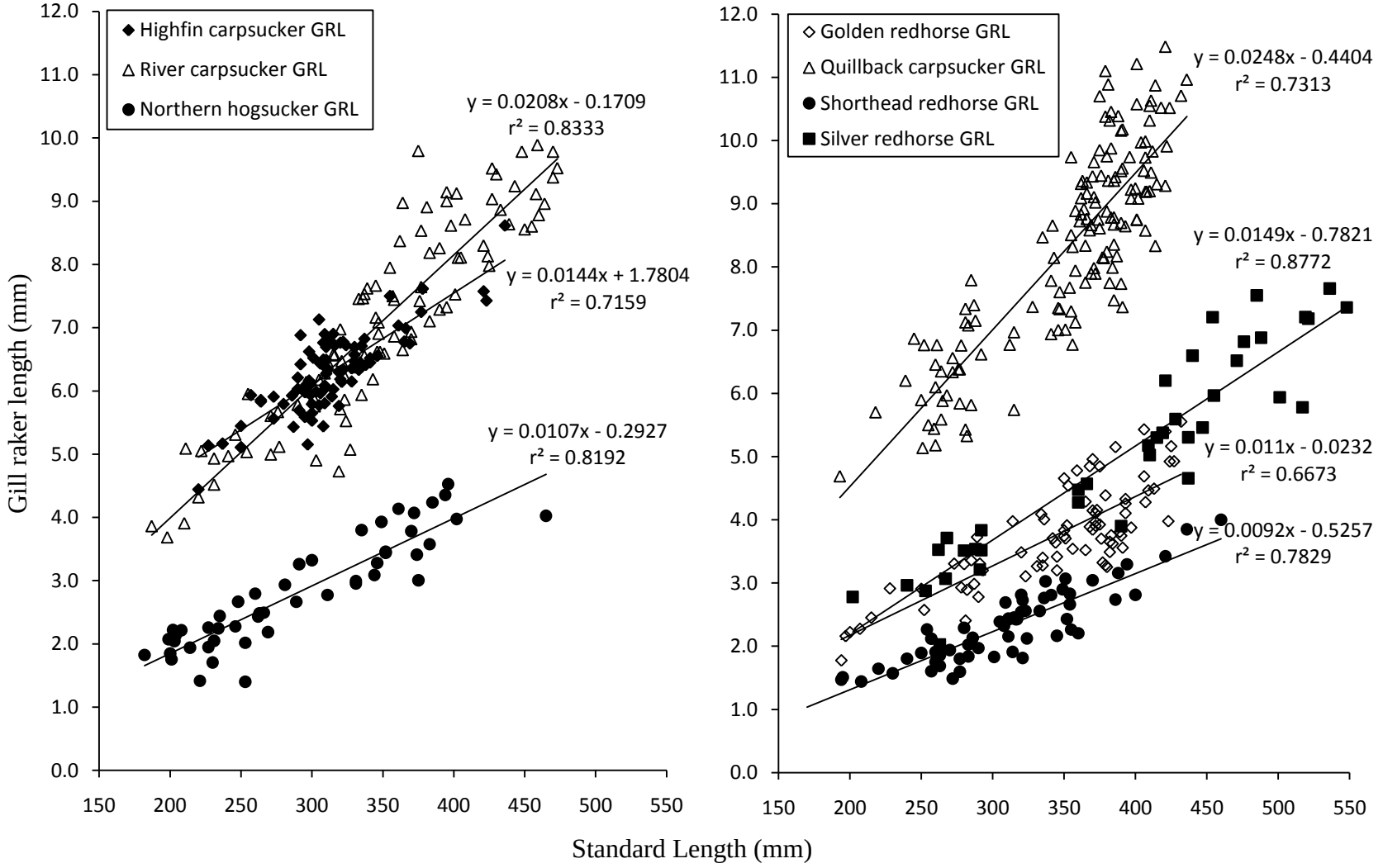

Figure 2.—Gill raker length (GRL) of catostomid spp. sampled from Iowa rivers, 2009.

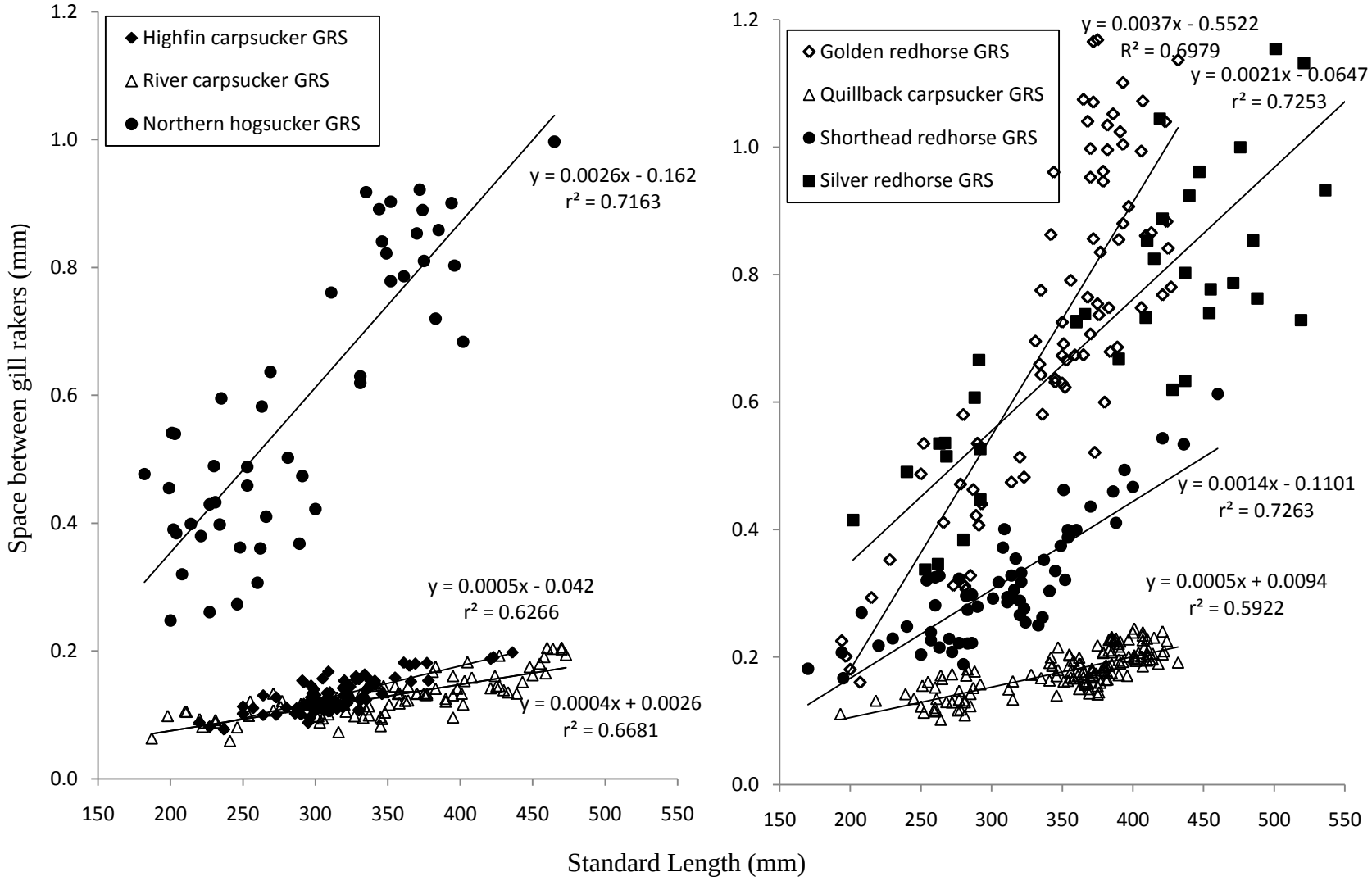

Figure 3.—Gill raker spacing (GRS) of catostomid spp. sampled from Iowa rivers, 2009.

CHAPTER FOUR

GENERAL CONCLUSIONS

The family *Catostomidae* is a very diverse and important part of the native fish assemblages of rivers in Iowa. Of the 17 catostomid species that occurred naturally in the state, two have been extirpated and the status of several others is unknown. Additionally, several of the species that have declined in Iowa have also declined or disappeared from other parts of their historic ranges. Any shift in distribution or decline in population size has most likely occurred because of anthropogenic impacts on resident aquatic ecosystems since suckers are not commercially harvested or promoted as game species. In Iowa the watersheds of rivers have been heavily modified by agriculture likely causing significant change to the available habitat, flow regimes and food web. These changes undoubtedly have had a significant impact on the diversity and structure of native fish assemblages.

Despite the large portion of riverine fish assemblage biomass that catostomids make up, relatively little study of their basic ecology and interactions has been performed. Even information as basic as precise age estimation is not available for some species. For example, all but one of the previous attempts at ageing species from the *Carpiodes* genera used a structure (scales) that has been shown to provide imprecise age estimates in many other species. Our results show the use of pectoral fin rays provides a more precise estimate of age for highfin carpsucker, quillback carpsucker, and river carpsucker and is a better choice for a future age validation study of *Carpiodes* spp.

The external similarity of many catostomid species makes it appear as though they should have significant overlap in food resource use. All of the sampled species have sub-

terminal mouths that are presumed to be well adapted to feeding on benthic invertebrates. Examination of food habits revealed that while benthic invertebrates constituted the majority of prey consumed, all of the sampled catostomid species also consumed invertebrates that are not typically associated with benthic substrates (e.g., chironomid pupae and ephmeroptera subimagos). Estimation of diet overlap between two species using Morista's index revealed that only three species combinations (highfin carpsucker and river carpsucker; quillback carpsucker and river carpsucker; and shorthead redhorse and silver redhorse) of the 21 possible combinations had significant overlap.

While previous research has shown that the diversity of invertebrates has declined in Iowa rivers our results indicate that the prey base appears to still be sufficiently numerous to support the current assemblage. The nutrient rich nature of the watersheds of Iowa rivers may help reduce diet overlap by allowing invertebrate species that are adapted to live in the heavily modified river channels sustain higher densities than nutrient poor watersheds.

Differences in gill raker length and spacing, and feeding ecology (i.e., specialized or generalized) among species allowed most of the species to utilize different food resources and reduced diet overlap. The observed differences in food habits are supported by differences in internal feeding morphology. For example, gill raker spacing was only significantly similar for comparisons within a genus. Also, with the exception of shorthead redhorse and northern hogsuckers, gill raker length was only significantly similar for comparisons within a genus.

Future studies of the diets of catostomids would benefit from simultaneous sampling of the diversity and density of invertebrates to truly examine their role in this fish assemblage. However, this would require additional time for the creation of a standardized

method for sampling the invertebrate assemblage of rivers that have widely varying habitat types, depth, and flow rates. Future research should also focus on the impacts of barriers to movement and habitat requirements on catostomid reproduction, as well as examine the food habits and gill raker morphology of less common catostomid species and their interactions with the species in the current study.